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The Salvo Equations: Tests and Applications

By Capt (Ret.) Wayne Hughes, Jr.
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73rd MORSS 21 June 2005

Relevance of Force-on-Force?

- OR rule: When there's a war, observe the war.
- Fighting terrorists is a special kind of war to observe.
- Still, the days of a sea sanctuary for the USN are waning or gone.
- We live in the missile age, and salvo equations were written for it.

Order

- The Salvo Equations.
- Value of Analytical Models.
- V & V [& A?].
- Recent Contributions to Understanding.
- Recent Influence.

The Equations

$$\Delta B = \frac{\alpha A - b_3 B}{b_1} \qquad \alpha = a_2 P_{ha}$$

$$\Delta A = \frac{\beta B - a_3 A}{a_1} \qquad \beta = b_2 P_{hb}$$

$A,\ B$ = number of combat units

$a_1,\ b_1$ = number of hits to put a unit out of action

$a_2,\ b_2$ = number of shots/salvo

$P_{ha},\ P_{hb}$ = probability of hit (no defense)

$a_3,\ b_3$ = number of shots eliminated

Ten Parameters!

Embellished Equations

$$\Delta B = \frac{\sigma_A \alpha A - \tau_b b_3 B}{b_1}$$

(ΔA symmetrical)

σ_A, σ_B = scouting effectiveness $0 < \sigma < 1$

τ_A, τ_B = defender alertness $0 < \tau < 1$

$$\frac{\Delta B}{B} = \frac{[\text{number of hits}]}{b_1 B}$$

Fraction OOA

Value of Analytical Models

- Manipulate to show relationships between parameters.

  --Minimal form of salvo equations has 10 parameters for both tactical commander and analyst to consider.

  --Stochastic version has 36 inputs and outputs.

- Reach parametric conclusions [If-then statements].
- Nice reference: T.W. Lucas and J.E. McGunnigle: "When is Model Complexity Too Much? Illustrating the Benefits of Simple Models With Hughes' Salvo Equations," *Naval Research Logistics*, April 2003.

Conclusions from Parametric Analysis

From the original article: “A Salvo Model of Warships in Missile Combat Used to Evaluate Their Staying Power,” *Naval Research Logistics*, March 1995.*

1. Unstable circumstances arise as the combat power of the forces grows relative to the survivability. (Stable means the persistence of victory by the side with the greater combat potential.)
2. Weak staying power is likely to be the root cause when instability is observed [or too few combat units].
3. Staying power is the ship design element least affected by the particulars of a battle, including poor tactics.
4. Numerical superiority is the force attribute that is consistently most advantageous. For example, if A’s unit striking power, staying power, and defensive power are all twice that of B, nevertheless B will achieve parity of outcome if has twice as many units as A.

*Republished in *Warfare Modeling*, MORS, 1995.

Development History

- Chase (1903) and Fiske formulation (1905)—for warships.
- Lanchester square and linear law (1915).
- Naval applications always more solidly based than for army or aerial combat.
- “Pulsed Power” observed to be best model in the era of the aircraft carrier (WWII).

  --One air wing sank one enemy CV (1942).

  --But not so in 1944, because of improved defense.
- Pulsed Power also observed in night surface combat, from destroyer torpedo salvoes (1942-43).
- Salvo equations with missiles have same structure, but

  --Salvoes more lethal than air wings or destroyers could deliver.

  --A small ship with missiles may put one or more big ones OOA.

Verification

- Basic Models are simplicity itself.
- Lanchester equations for ground combat has many variations, not simple.
- Salvo equations are recent so still easy to verify, even the stochastic and heterogeneous force versions.

Validation of Salvo Equations

- Lt Thomas Beall, “The Development of a Naval Battle Model and Its Validation Using Historical Data,” NPS thesis, 1990.

  --14 battles of WWI and WWII, gunfire and torpedoes, “TPBE” input.

- Lt Jeffrey Cares, “The Fundamentals of Salvo Warfare,” NPS thesis, 1990.

  --Point defense only, NAVTAG simulation used as “real world.” Defines sump effect and combat entropy.

- Lt Ray Snell, “Countertargeting in Naval Salvo Warfare,” NPS thesis, 1990.

  --Purpose is to measure effects of jamming and decoys. Scenario is air attacks against CVBG.

- General Conclusion: Simple salvo equations are sufficient to replicate a battle and get similar results.

Accreditation Relevant?

- Incompleteness—Accreditation is "provisional."
  --Pat Sanders, *Military Modeling for Decision Making*, Chapter 14.
- Input domain—a range limit on inputs.
  --Clay Thomas, *Military Modeling for Decision Making*, Chapter 13.
- Technical limits—e.g., statistical independence.
- Physical vs. human entities vs. competitive situations. And human vs. machine learning.
  -- Peter Denning, "Modeling Reality," Phalanx, 2004.

Conclusion: Salvo equation accreditation is moot.

Recent Applications

- John McGunnigle, "Information on Information: Comparing the Military Values of Force Advantage and Information Advantage," NPS thesis, 1999.
- Michael Johns, "Heterogeneous Salvo Model for the Navy After Next," NPS thesis, 2001.
- Michael Armstrong, "Effects of Lethality in Naval Combat Models," *Naval Research Logistics*, Feb 2004.
- _____, "A Stochastic Salvo Model for Naval Surface Combat," *Operations Research*, Sep 2005.
- Kevin Haug, "Using Hughes' Salvo Model to Examine Ship Characteristics in Surface Warfare," NPS thesis, 2004.
- Michael Armstrong, "A Stochastic Model Analysis of the Battle of the Coral Sea," in review to be published, 2005.

Recent Applications [2]

M. J. Armstrong's "Effects of Lethality in Naval Combat Models" shows the range of battle outcomes as a function of offensive firepower (shots), defensive capability, and staying power.

Recent Applications [3]

M.J. Armstrong: general case

Figure 2. Losses to Each Side in High Lethality Combat

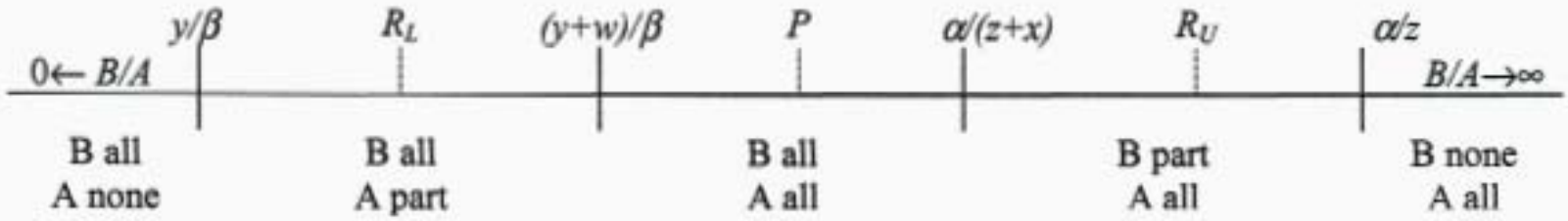
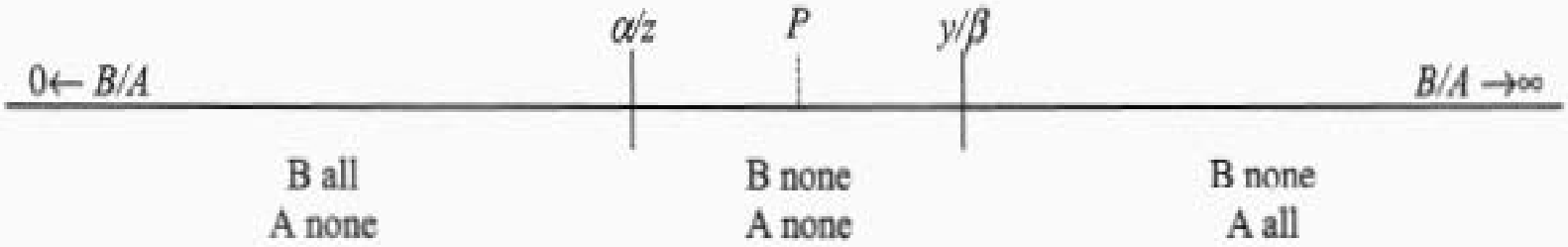


Figure 4. Losses to Each Side in Low Lethality Combat



Armstrong Specific Application

Figure 5. % Force Surviving in Low Lethality Combat Example

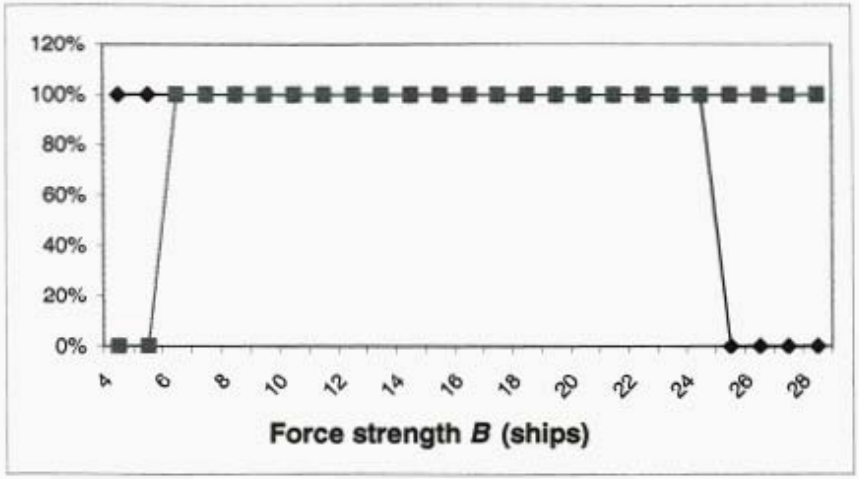
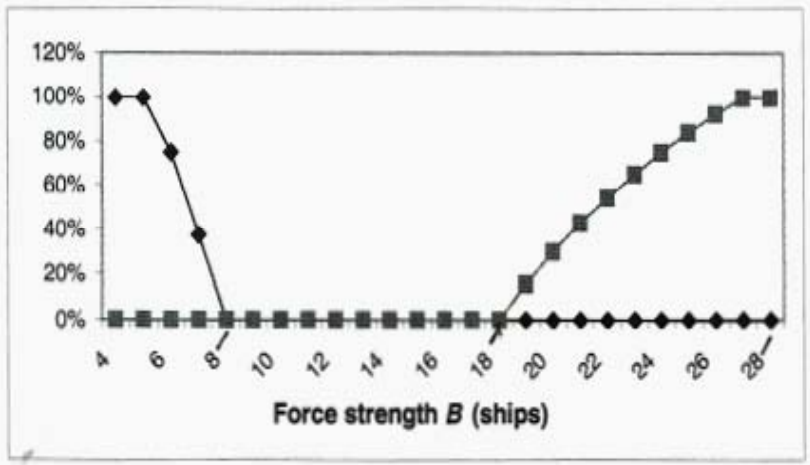


Figure 7. % Force Surviving in High Lethality Combat Example



Other Recent Applications

Separately, Armstrong confirms Hughes' tactical insights re the WWII carrier battles using the stochastic salvo equations:

From Armstrong: ". . .Coral Sea"

"To study each of these [4] alternatives, we adjust the inputs to our model . . .and then examine the model outputs to determine the likely impact of the change. . .Overall these result can be interpreted as supporting the proposition [of Hughes] that in 1942 naval warfare the offense was inherently superior to the defense."

Base case shows [again] that "Simple salvo equations are sufficient to replicate a battle and get similar results."

Footnote: By 1944, the defense had gotten stronger and the full salvo equations must be used.

Recent Influence

- NPS *Sea Lance Project*, SEA students, Jan 2001.
- NPS *Crossbow Project*, SEA students, Jan 2002.
- Singapore: “An Analysis of Distributed Combat Systems,” CPT Keith Ho, NPS thesis, Dec 2001.
- OFT: *Alternate Fleet Architecture Designs*, Jan 2005.
- CNO Strategic Studies Group XXN: “Beyond Maritime Supremacy,” Results, June 2006.
- Canadian Navy: “Starting Over: The Canadian Navy and Expeditionary Warfare,” Cdr K.P. Hansen, *Canadian Naval Review*, Spring 2005.

Recent Influence [2]

- Office of Force Transformation's "Alternative Fleet Architecture Designs" Study advocates mix of big and small combatants.
- They are complementary for future missions.
- Small combatants screen big combatants when littoral fighting is likely and keep Navy numbers up.
- Smalls go beyond LCS to Sea Fighter (X-Craft) Size, 1,000 tons. Designs are lethal to approximately 20 miles.
- Study's SSC-1000 is 1,000 tons, sea base supported.
- Study's dramatically smaller VSC-100 is 100-ton combatant, mother ship supported.
- Espouses development, construction, and experiment at sea (because combatants relatively cheap).
- Also advocates UVs of many configurations.

Recent Influence [3]

- Hansen's article offers same insights for a reborn Canadian Navy.*
- "Starting Over . . ." means based on classic navy functions [by Ken Booth].
- Smaller scale in numbers and ship size than USN.
- . . . and only a few "large" combatants.

  --"These large power-projection ships should employ manned aircraft and be capable of carrying troops." They replenish small combatants.
- More warships should be simpler, smaller, more maneuverable, and stealthier, and carry much firepower.

  --"The small warship must also be able to accommodate a small landing party [for special operations and boarding] and be able to operate remotely piloted vehicles."

* Hansen is at the Canadian Forces College, but is not writing official policy.

Recapitulation

- Salvo equations are so simple they can be understood, yet not be misconstrued for more than they are.
- For conceptualizing future design, return to my original intent (1995).

"Estimating the value of warship attributes has always been of central importance to a navy. There was a time when firepower, staying power, speed, and endurance were debated publicly, energetically, and with the knowledge that 'you cannot have everything.'"

". . .two dilemmas. First, when similar quantities of ordnance strike similar warships, the variance from the mean in the amount of damage is quite large (Humphrey, Hughes)." Second, even if you could predict precisely the damage caused by a hit "the difficult question would remain: What is the military worth of staying power relative to its other combat attributes?"

Recapitulation [2]

- Since one can't predict the venue of future battles, he can't predict the values of today's design attributes. But he must try. Mahan said:

  "A country can, or will, pay only so much for its war fleet. That amount of money means so much aggregate tonnage. How shall that tonnage be allotted? And especially, how shall the total tonnage be invested . . . Will you have a very few big ships, or more numerous medium ships?"

- Bradley Fiske, who did calculations, preferred numbers and fast firing guns in 1905.
- Salvo equations show number of combatants as the best attribute.